



Exoplanetary systems around M dwarfs with radial velocities: use of multidimensional Gaussian process to quantify the stellar noise

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Summary



- Re-Analysis of 2 CARMENES targets with published planets: GJ 338B & GJ 1002
- Multi GP approach
- Comparing results with the literature
- Conclusions

Methodology



Pyaneti¹ code

- Multidimensional Gaussian process²

Quasic-Periodic Kernel:

$$\gamma_{QP}(t_i, t_j) = A^2 \exp \left\{ -\frac{\sin^2[\pi(t_i - t_j)/P_{GP}]}{2\lambda_p^2} - \frac{(t_i - t_j)^2}{2\lambda_e^2} \right\}$$

$\left[\begin{array}{l} - P_{GP} \text{ (Rotacional period of the star)} \\ - \lambda_e \text{ (Lifespan of the active regions)} \\ - \lambda_p \text{ (Active region distribution)} \end{array} \right.$

Simultaneous fit RV + Activity \longrightarrow

$$\begin{aligned} \text{RV} &= A_0 G(t) + A_1 \dot{G}(t) \\ \text{H}_\alpha &= A_2 G(t) + A_3 \dot{G}(t) \end{aligned}$$

Analysis and results

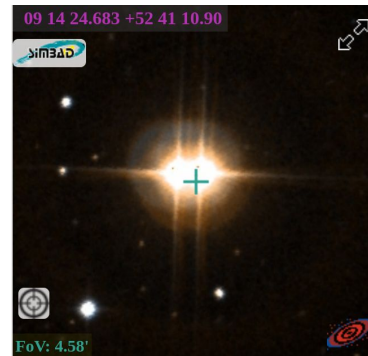
GJ 338 B

Spectral type M0.0 V

Stellar parameters:

- $M_{\star} = 0.64 \pm 0.07 M_{\odot}$
- $R_{\star} = 0.58 \pm 0.03 R_{\odot}$
- $T_{\text{eff}} = 4005 \pm 51 \text{ K}$
- $d = 6.334 \text{ pc}$
- $P_{\text{rot}} = 16.61 \pm 0.04 \text{ d}$

González-Álvarez et al. (2020)

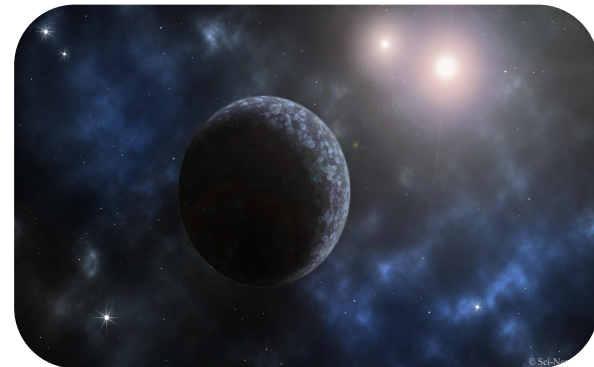


GJ 338 B b

Super-Earth

Planetary parameters:

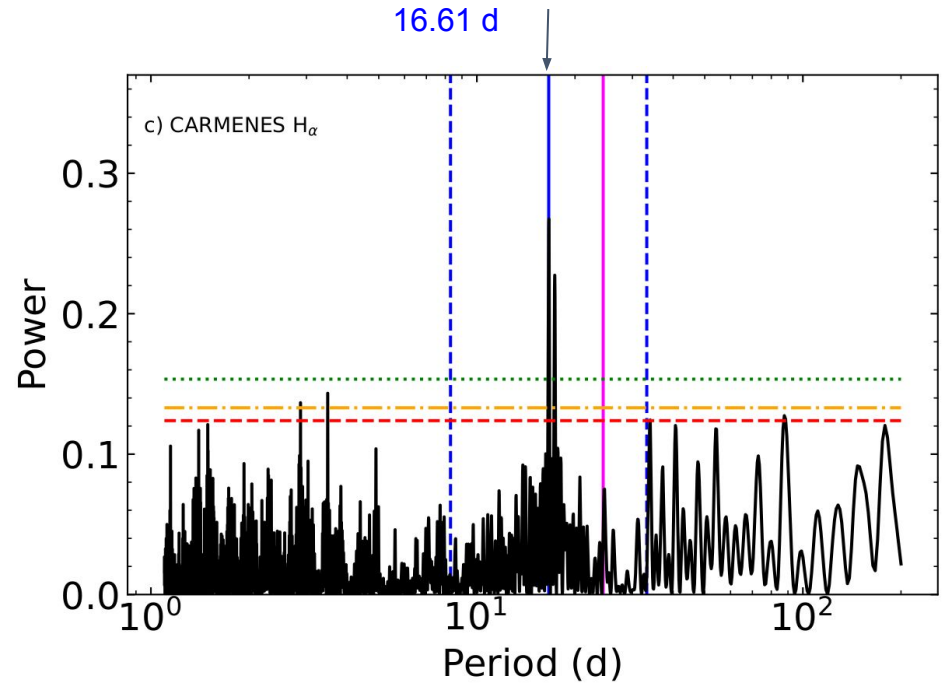
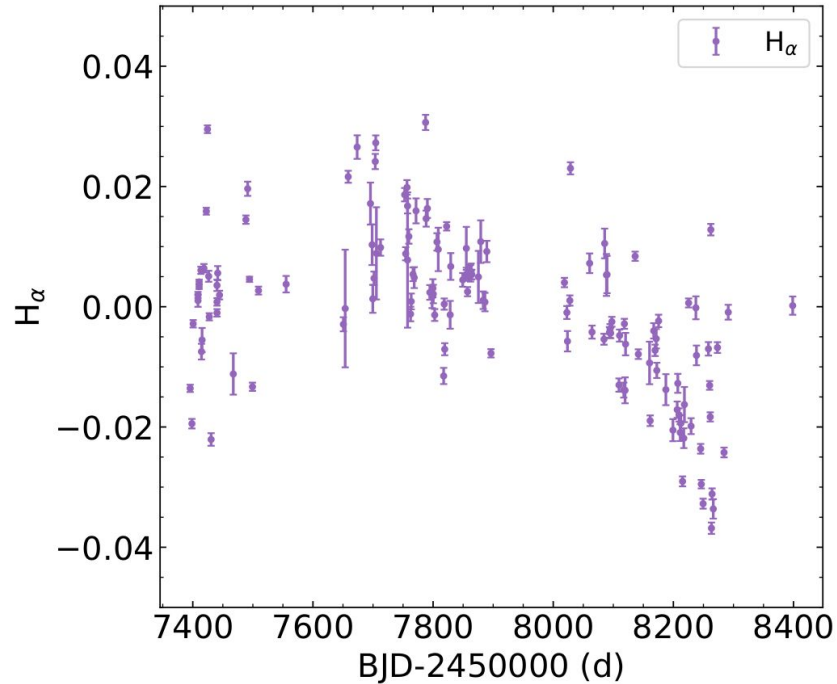
- $M_{\text{p}} = 10.27 \pm 1.4 M_{\oplus}$
- $P_{\text{p}} = 24.45 \pm 0.02 \text{ d}$



GJ 338 B (GLS $H\alpha$)



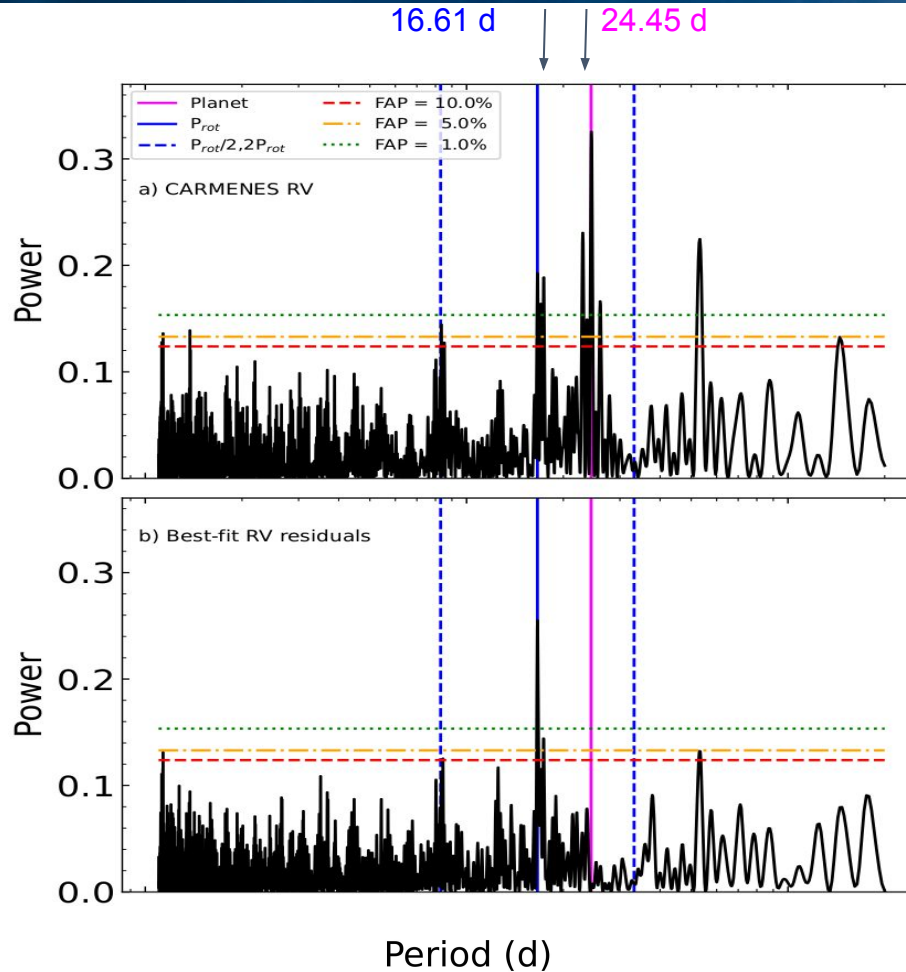
CARMENES DATA



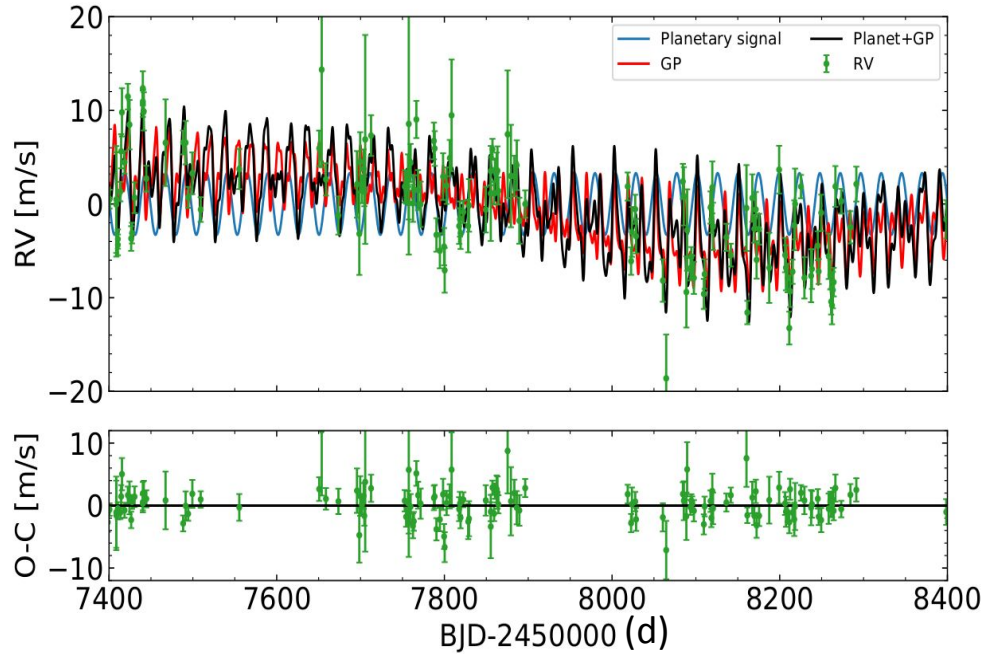
GJ 338 B (GLS RVs)



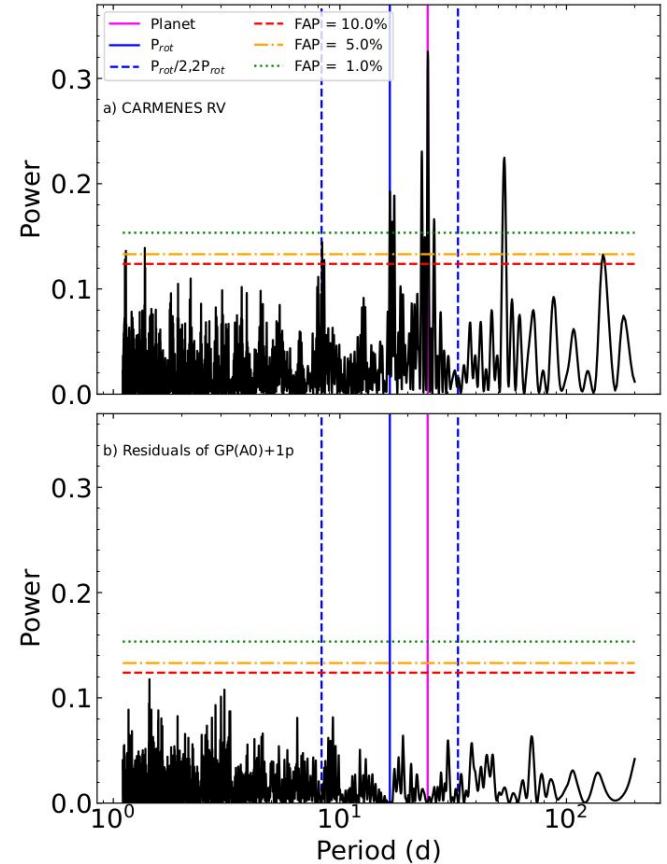
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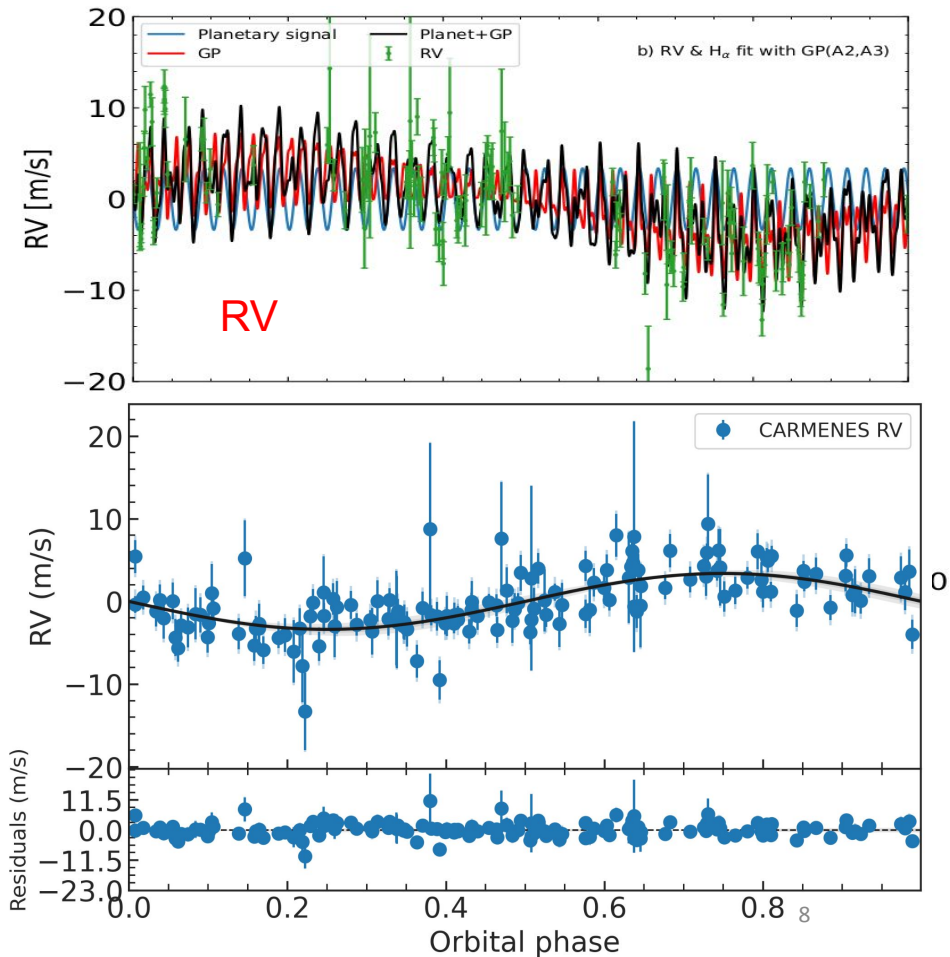
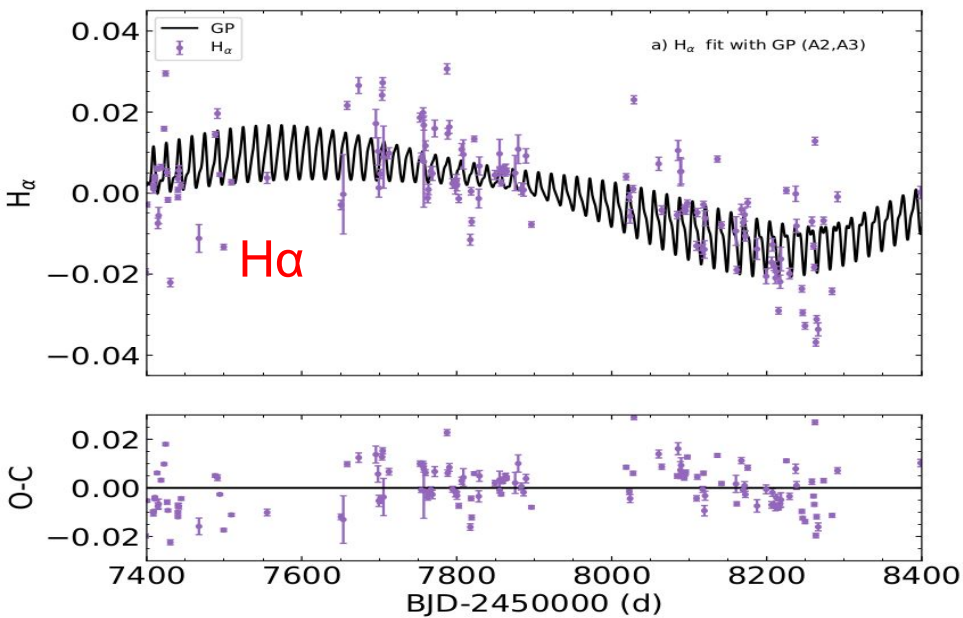
GJ 338 B (GP+RV)



1pl+GP model



GJ 338 B (Multi-GP RV+H α)



Multi-GP+1pl

GJ 338 B b



RV+GP VS RV+Multi-GP

GJ 338B b		
Parameter	RV+GP fit	Multi-GP fit
K [m s ⁻¹]	$3.29^{+0.33}_{-0.32}$	$3.38^{+0.37}_{-0.47}$
P [days]	$24.384^{+0.027}_{-0.024}$	$24.399^{+0.039}_{-0.030}$
$m \sin i$ [M_{\oplus}]	$11.03^{+1.39}_{-1.35}$	$11.31^{+1.56}_{-1.75}$
a [au]	0.1421 ± 0.0052	0.1418 ± 0.0052
S [S_{\oplus}]	3.88 ± 0.53	3.88 ± 0.53
T_{eff} [K]	357 ± 85	357 ± 85
RMS res [m/s]:	2.98	2.8

$$P_{\text{rot (lit)}} = 16.61 \pm 0.04 \text{ d}$$

$$P_{\text{rot}} = 16.564^{+0.177}_{-0.081} \text{ d}$$

Results in González-Álvarez et al. (2020)

$$K \text{ (m/s)} = 3.07 \pm 0.37$$

$$P \text{ (days)} = 24.45 \pm 0.02$$

$$m_P \sin i (M_{\oplus}) = 10.27 \pm 1.4$$

Analysis and results

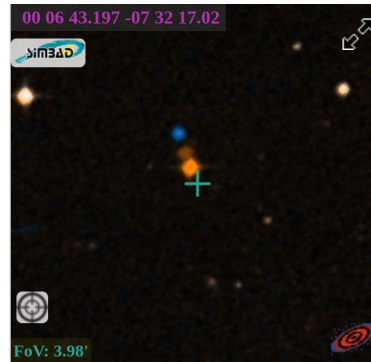
GJ 1002

Spectral type M5.5 V

Stellar parameters:

- $M_{\star} = 0.12 \pm 0.01 M_{\odot}$
- $R_{\star} = 0.137 \pm 0.005 R_{\odot}$
- $T_{\text{eff}} = 3024 \pm 52 \text{ K}$
- $d = 4,84 \text{ pc}$
- $P_{\text{rot}} = 126 \pm 15 \text{ d}$

Suárez-Mascareño et al. (2023)



GJ 1002 b

Terrestrial

Planetary parameters:

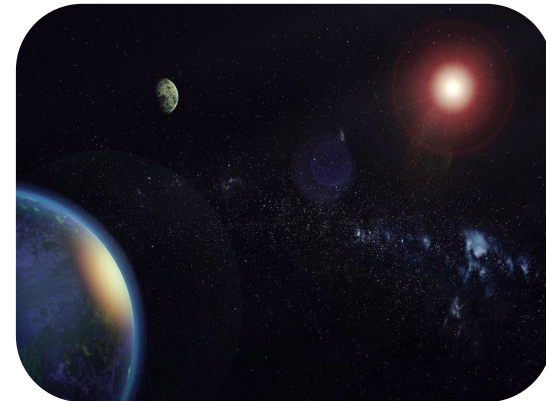
- $M_p = 1.08 \pm 0.13 M_{\oplus}$
- $P_p = 10.34 \pm 0.03 \text{ d}$

GJ 1002 c

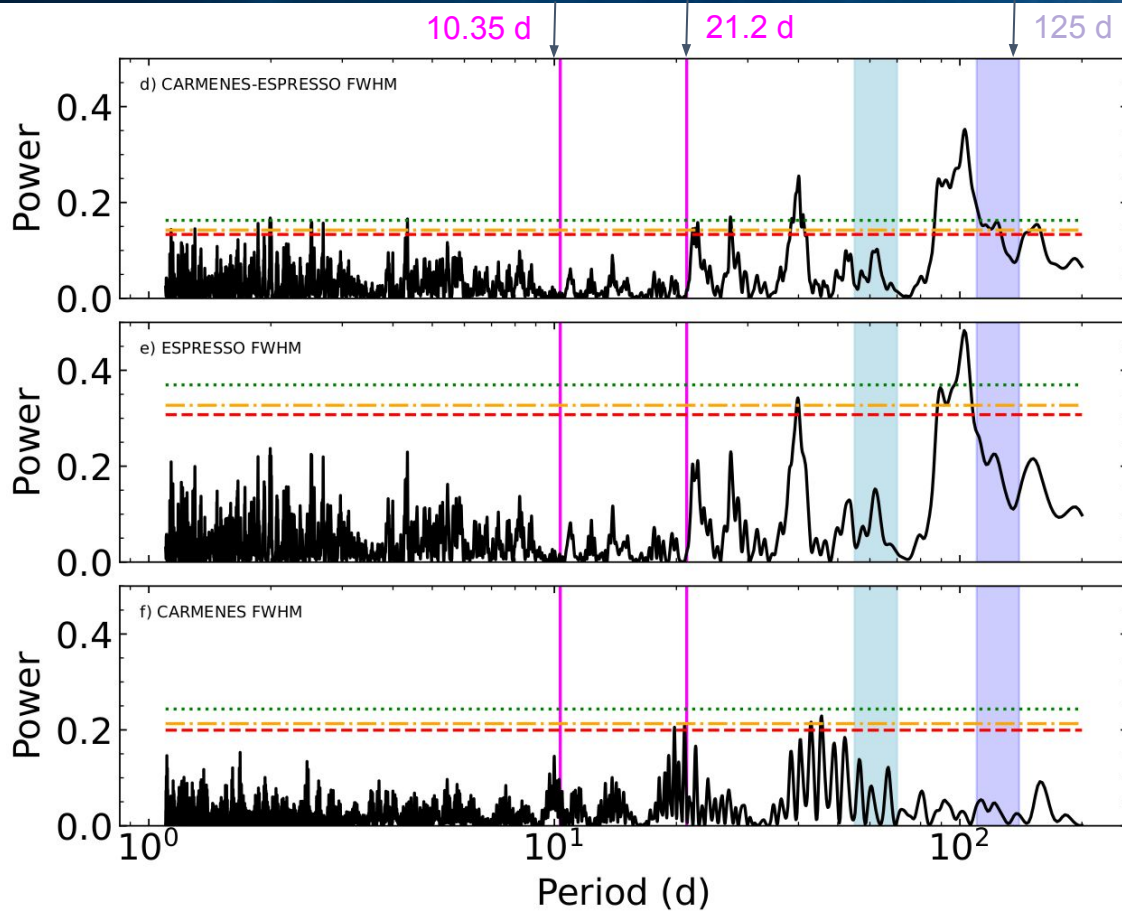
Terrestrial

Planetary parameters:

- $M_p = 1.36 \pm 0.17 M_{\oplus}$
- $P_p = 21.20 \pm 0.01 \text{ d}$



GJ 1002 (GLS FWHM)

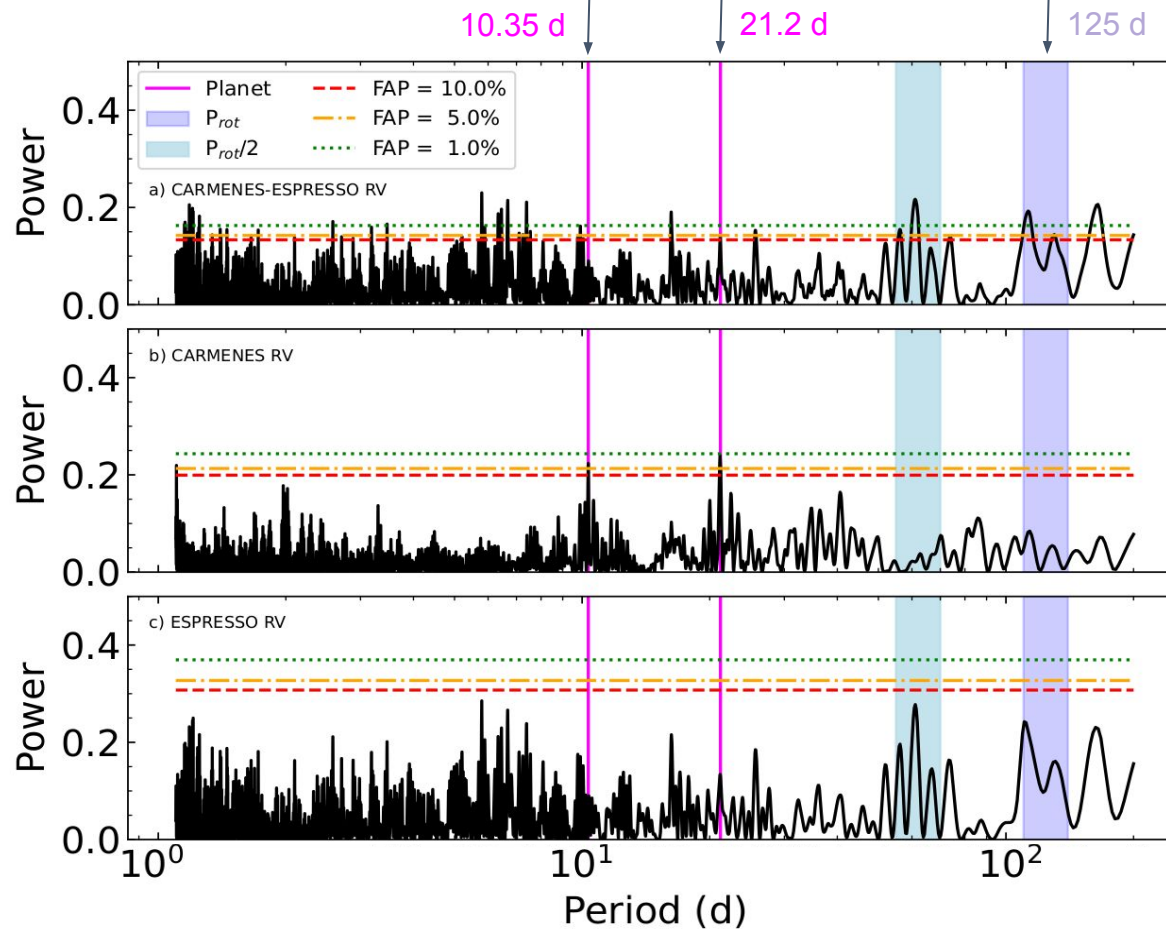


CARMENES +
ESPRESSO

ESPRESSO

CARMENES

GJ 1002 (GLS RVs)



CARMENES +
ESPRESSO

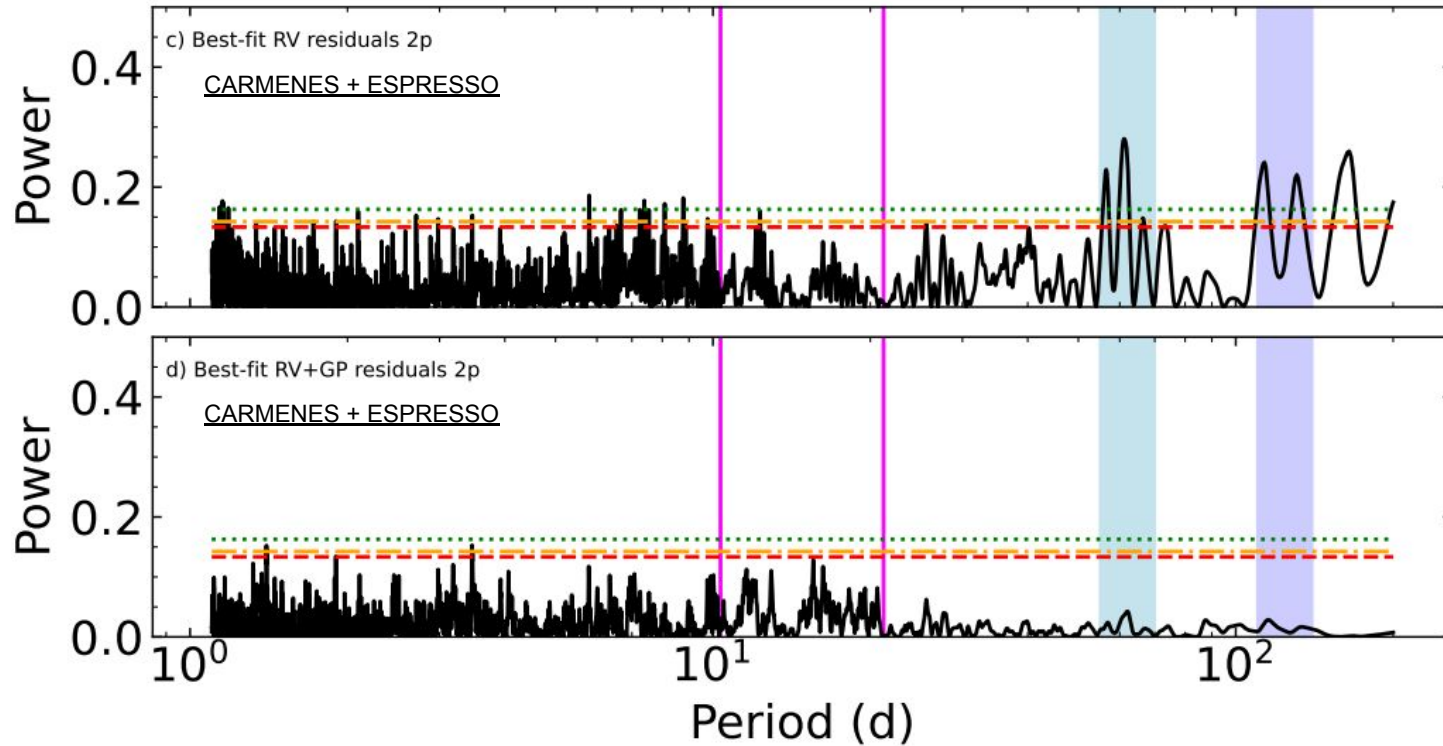
CARMENES

ESPRESSO

GJ 1002 (GLS RVs)



GLS RESIDUALS



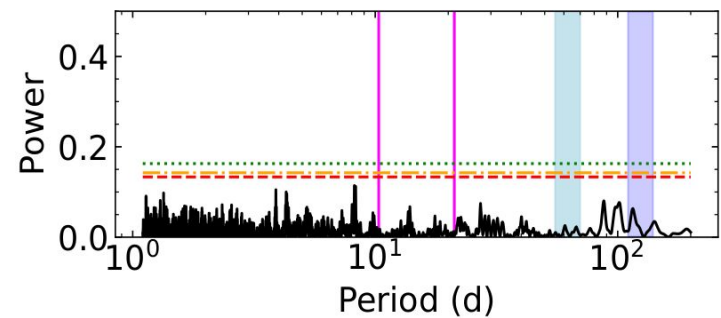
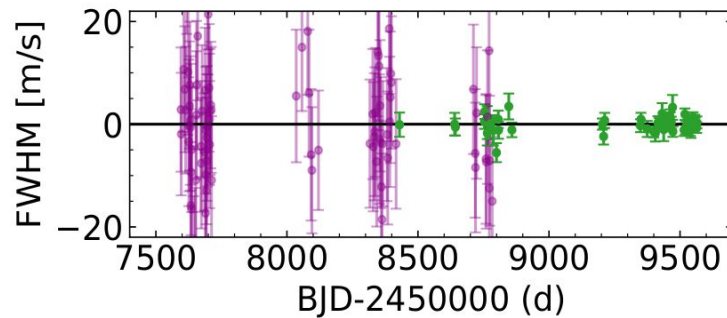
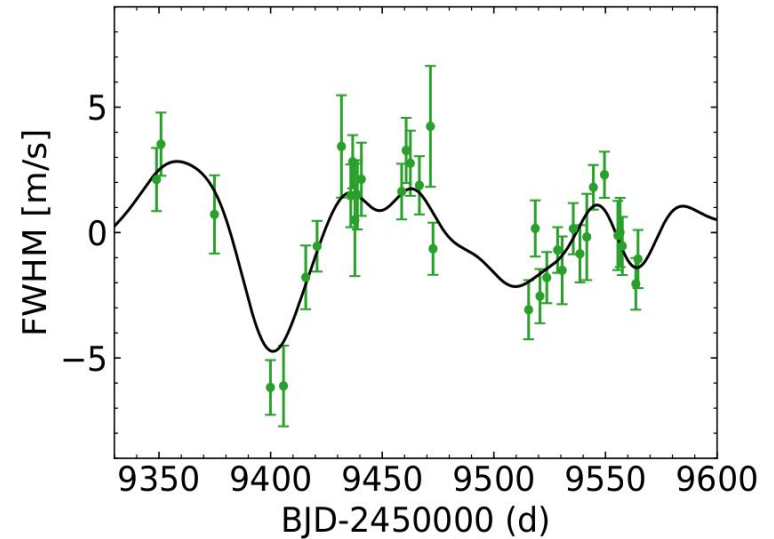
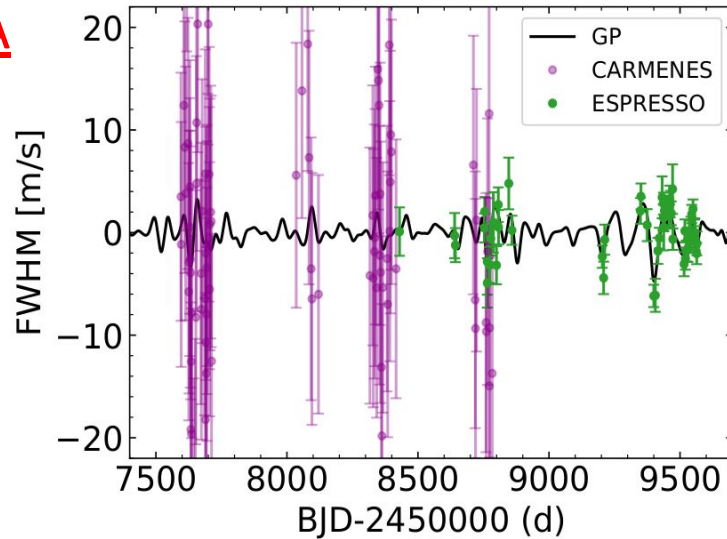
GJ 1002 (Multi-GP RV+FWHM)



FWHM
DATA

CARMENES + ESPRESSO

Multi-GP+1pl



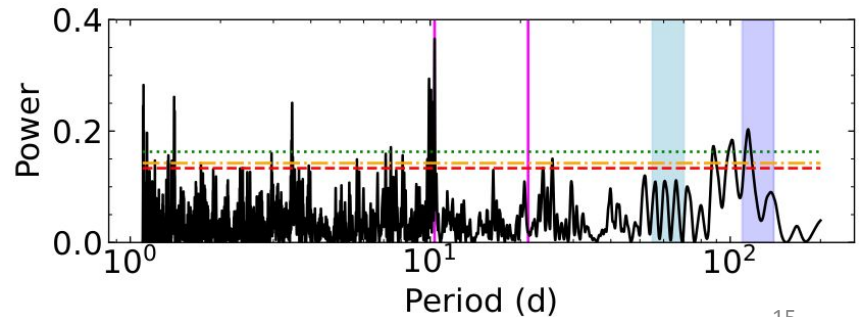
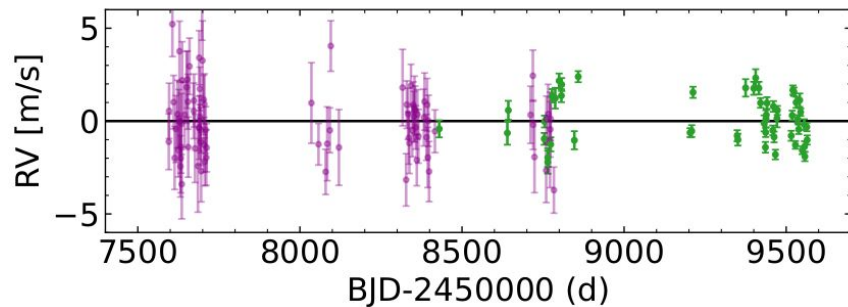
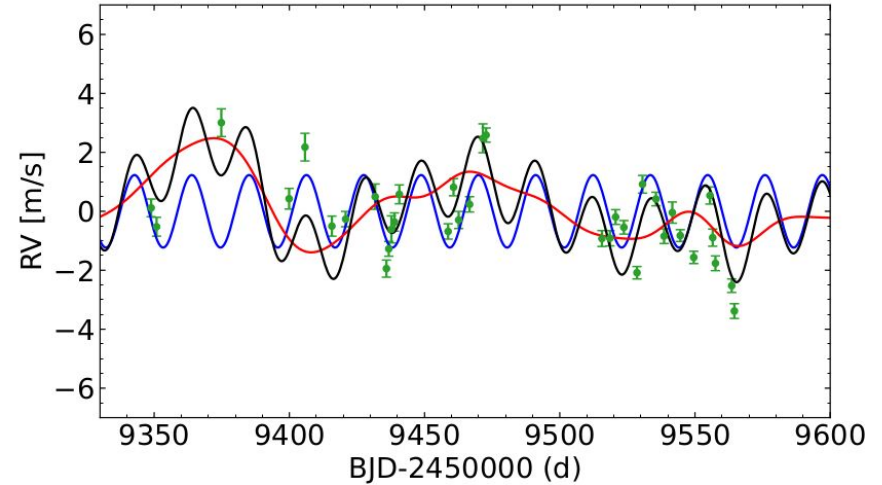
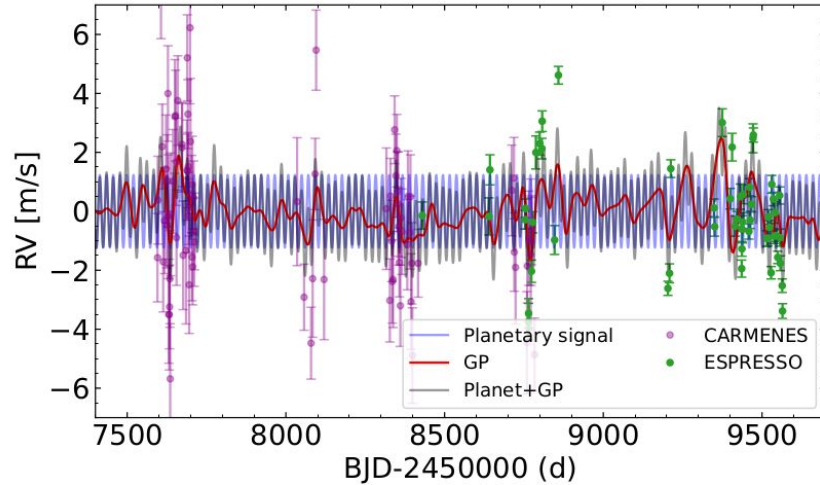
GJ 1002 (Multi-GP RV+FWHM)



RV DATA

CARMENES + ESPRESSO

Multi-GP+1pl



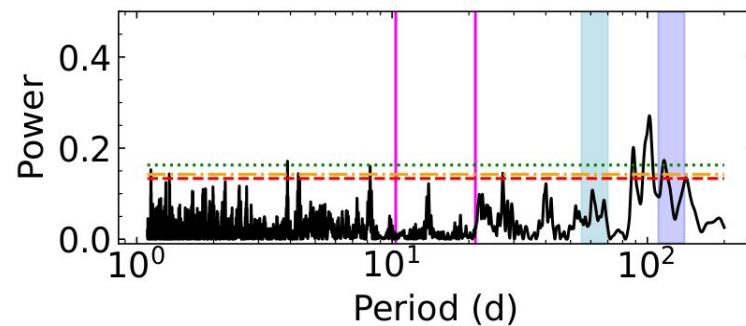
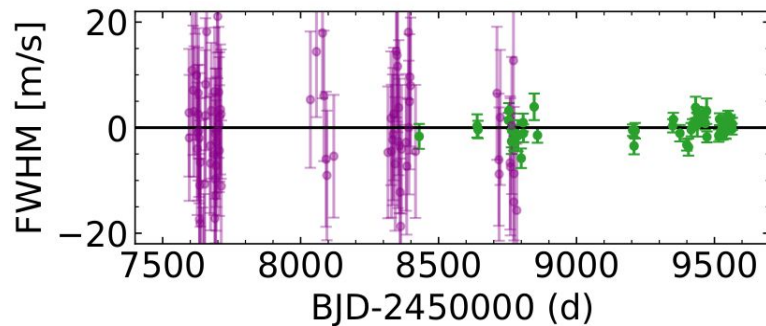
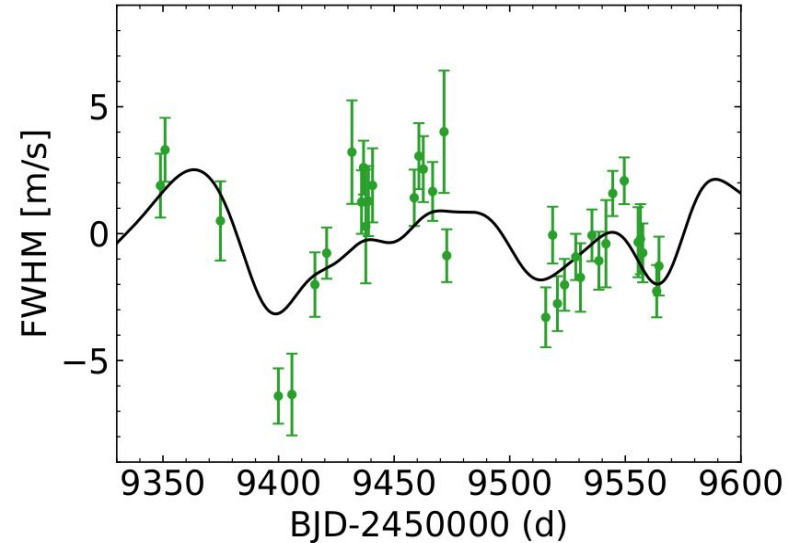
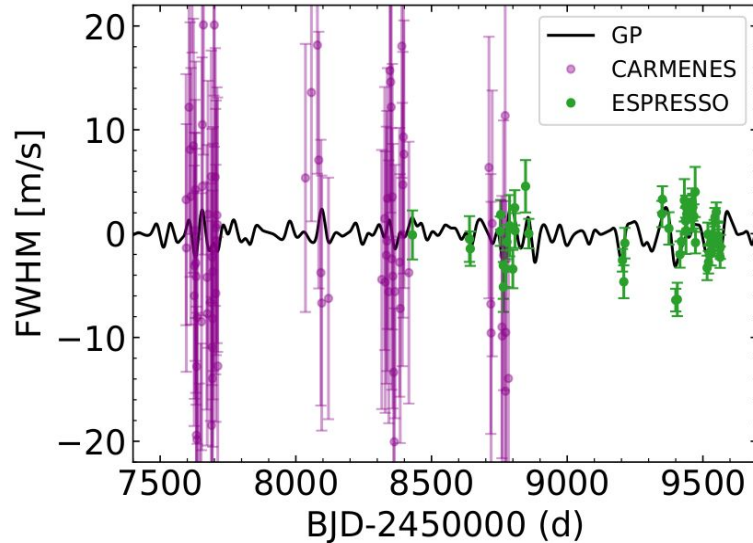
GJ 1002 (Multi-GP RV+FWHM)



FWHM
DATA

CARMENES + ESPRESSO

Multi-GP+2pl



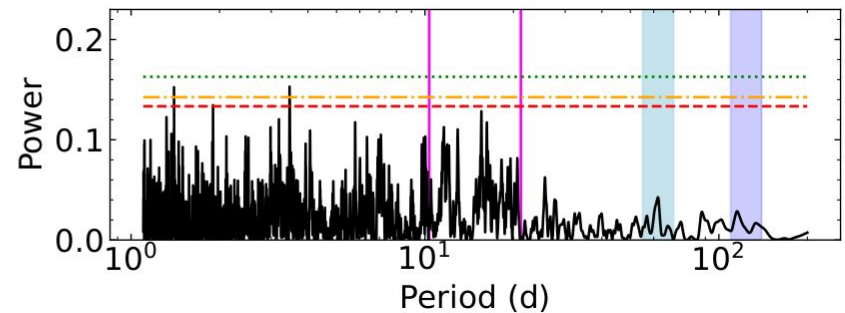
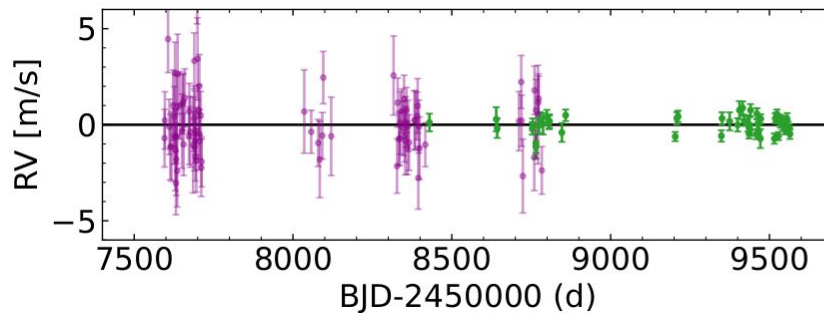
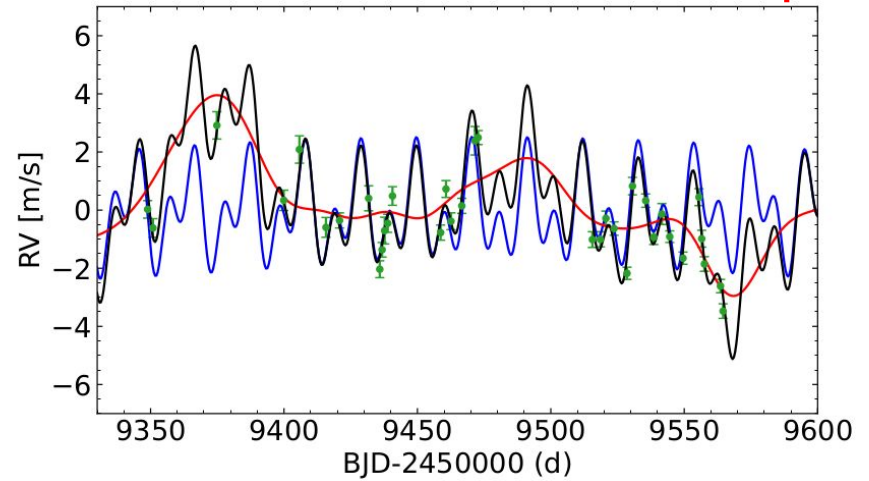
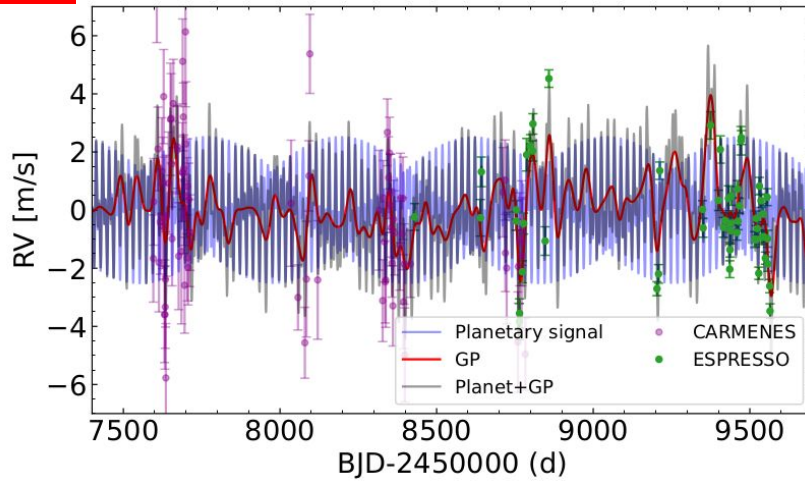
GJ 1002 (Multi-GP RV+FWHM)



RV DATA

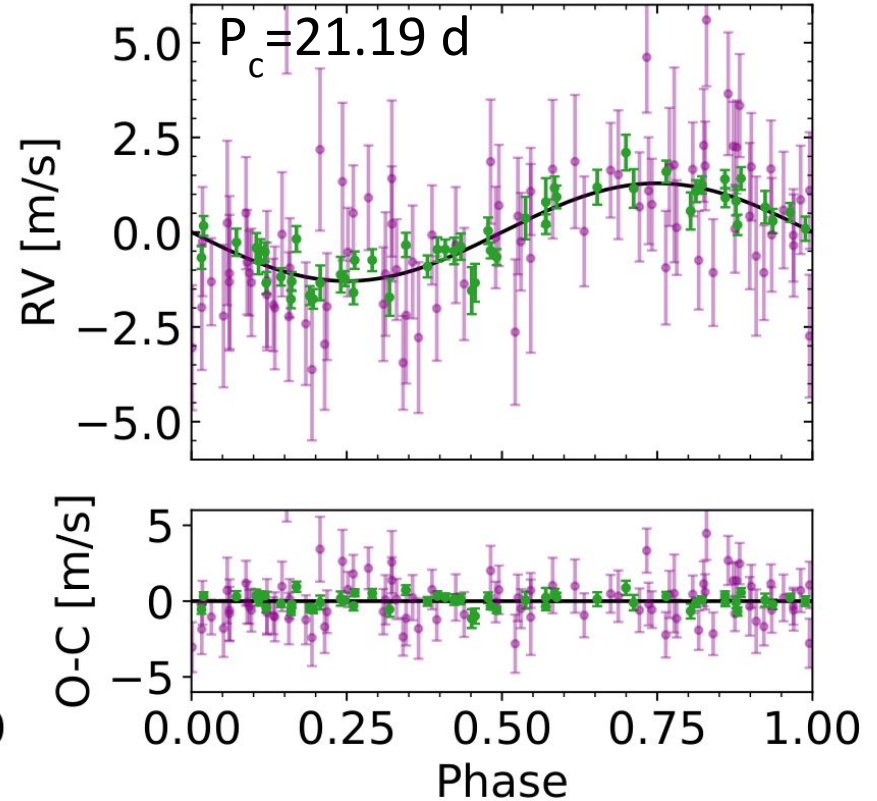
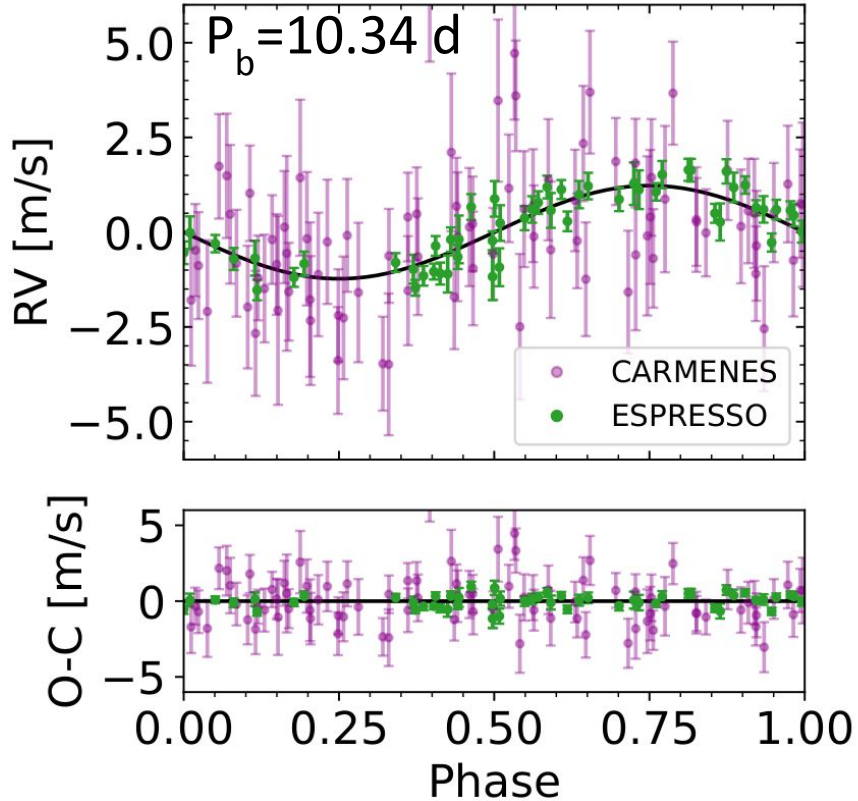
CARMENES + ESPRESSO

Multi-GP+2pl



GJ 1002 b & c

RV PHASE FOLDED

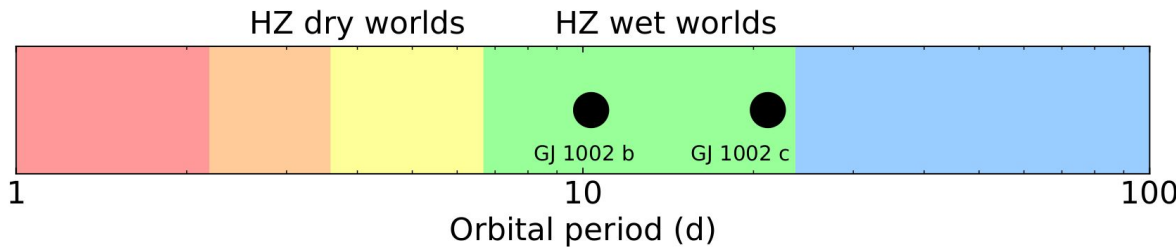


GJ 1002 b & c



Parameter	GJ 1002 b			GJ 1002 c		
	Best RV fit	Multi-GP fit	Suárez-Mascarero et al. (2023)	Best RV fit	Multi-GP fit	Suárez-Mascarero et al. (2023)
K [m s^{-1}]	1.23 ± 0.25	$1.28^{+0.16}_{-0.17}$	1.31 ± 0.14	$1.17^{+0.23}_{-0.22}$	$1.26^{+0.17}_{-0.34}$	1.30 ± 0.14
P [days]	$10.34131^{+0.00051}_{-0.16651}$	$10.34173^{+0.01161}_{-0.00022}$	10.346 ± 0.027	$21.1980^{+0.0020}_{-0.0505}$	$21.1989^{+0.0010}_{-0.0015}$	21.202 ± 0.013
$m \sin i$ [M_{\oplus}]	$1.02^{+2.01}_{-0.22}$	$1.06^{+0.21}_{-0.15}$	1.08 ± 0.13	$1.23^{+0.25}_{-0.43}$	$1.33^{+0.19}_{-0.37}$	1.36 ± 0.17
a [au]	$0.0458^{+0.0013}_{-0.0014}$	0.0458 ± 0.0013		0.0739 ± 0.0021	0.0739 ± 0.0021	
S [S_{\oplus}]	$0.674^{+0.065}_{-0.067}$	0.674 ± 0.66		0.259 ± 0.025	0.259 ± 0.025	
T_{eff} [K]	230^{+19}_{-20}	230 ± 18		181 ± 20	182 ± 20	

RMS res [m/s]: 1.91 1.35 1.30 1.91 1.35 1.30

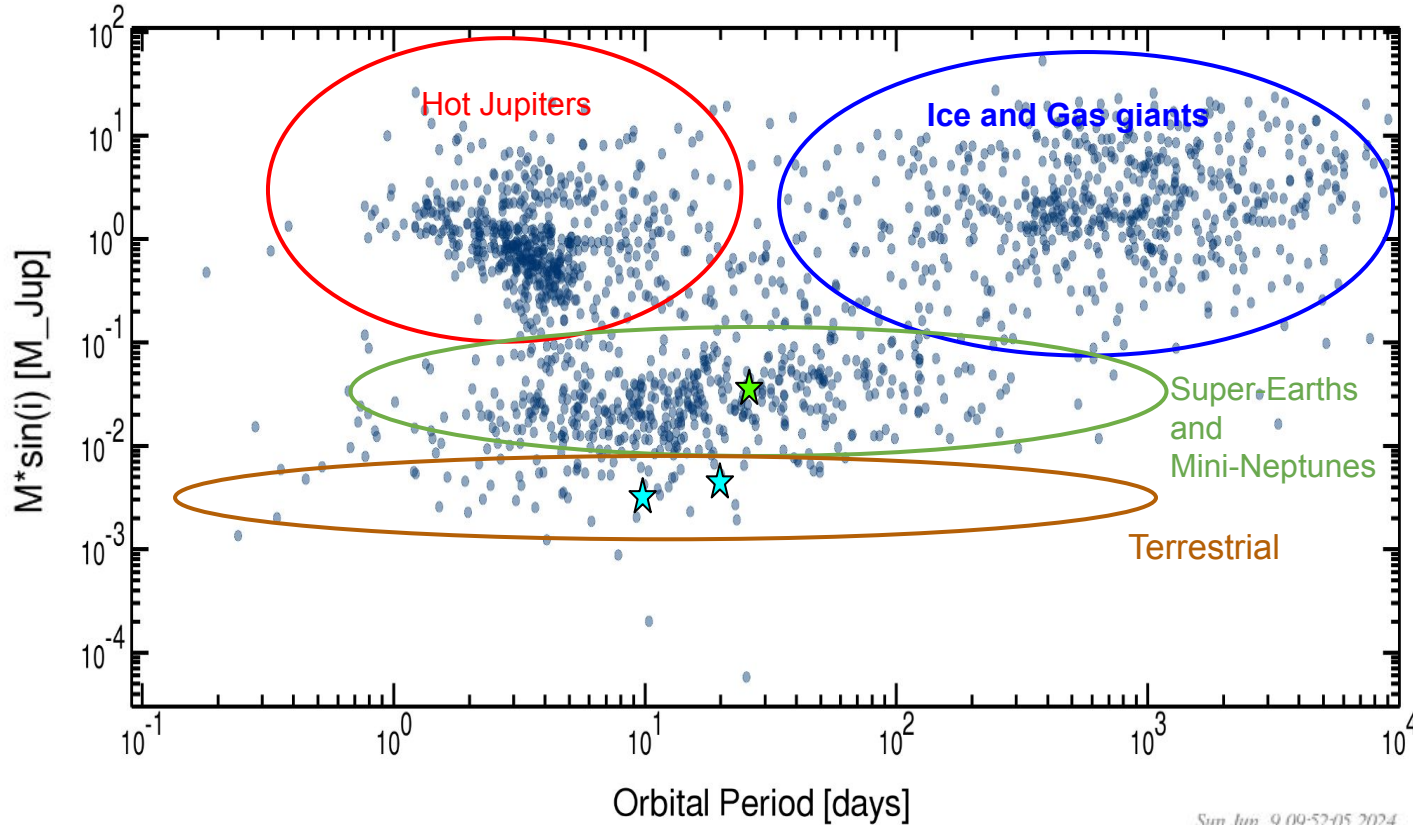


$P_{\text{rot}}(\text{lit}) = 126 \pm 15$ d

$P_{\text{rot}} = 127^{+21}_{-17}$ d

Low activity star → Better modeled with GP

Discussion



Sun Jun 9 09:52:05 2024

- ★ GJ 1002 b & c
- ★ GJ 338B b

Conclusions



- We re-obtained all the planetary parameters of each system.
- Using Multi-GP in RV+activity indicators is necessary to detection of Earth like planets in the HZ of GJ 1002.
- Multidimensional Gaussian Processes (Multi-GP) are emerging as a key tool for modeling stellar activity in M-type stars.
- Multi-GP have proven particularly effective in more active stars, where stellar activity reflected in FWHM, $H\alpha$, and RV can mask planetary signals.
- A more detailed study with additional systems and the inclusion of new kernels, such as dSHO, is necessary to better model and account for stellar activity.